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(71) Applicant: Nortel Networks Limited
Montreal, Quebec H2Y 3Y4 (CA)

(72) Inventor: Roberts, Kim B.
Nepean, Ontario K2R 1C6 (CA)

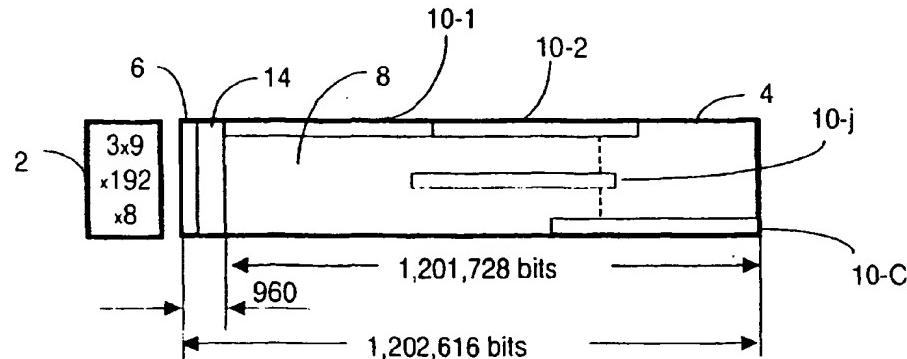
(74) Representative: Ertl, Nicholas Justin
Elkington and Fife,
Prospect House,
8 Pembroke Road
Sevenoaks, Kent TN13 1XR (GB)

(54) Mapping arbitrary signals into sonet

(57) A synchronizer/de-synchronizer maps continuous format signals of an arbitrary rate into frames of pre-selected single common rate, such as SONET frames, with no bits changed and very little jitter or wander added. In this way, the continuous format signal may be carried transparently as a tributary of a SONET network. Each frame comprises a definite number of fixed stuff bits (6, 14) including transport overhead bits and re-

minder fixed stuff bits. A frame also comprises an adjustable number of adaptive stuff bits (8), resulting from the phase difference between the arbitrary rate and the common rate. A mapping function is performed in a tributary unit shelf of a SONET transport shelf, and the reverse mapping function is performed in a similar way at the far end of a SONET connection. The stuff bits are spread uniformly within the frame.

FIGURE 1B



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Description

[0001] The invention is directed to transparent transportation of data signals with a continuous format, and in particular to a method for mapping arbitrary continuous signals into a SONET frame.

5 [0002] Rapid provisioning of a customer's requested service is a valuable network function. There can be a large range of possible bit-rates for such services, or indeed the service and its bit-rate may not even have been defined when the network equipment is installed. Therefore, rapid provisioning of a service of arbitrary bit-rate is a valuable function.

10 [0003] Data transmission formats can be divided into SONET, other continuous formats, and burst formats. Burst formats do not have a continuous clock, transmission of such signals do not require any given phase relationship between bursts. On the other hand, the phase of the clock of continuous formats has continuity under normal conditions, and the frequency of the clock is bounded. Examples of such bounds are $\pm 20\text{ppm}$ (parts per million of the bit rate) and $\pm 100 \text{ ppm}$.

15 [0004] The dominant signal format in the fiber optic networks follows the synchronous standard SONET in North America and SDH elsewhere. In this specification, SONET is defined to include SDH. SONET enables multiplexing, adding and dropping, and general transportation of signals. For a service, being able to be easily transported by a SONET network is a valuable attribute, in that it enables the network providers to make use of the large base of installed SONET-compatible equipment.

20 [0005] SONET is a physical carrier technology, which can provide a transport service for ATM, SMDS, frame relay, T1, E1, etc. As well, operation, administration, maintenance and provisioning (OAM&P) features of SONET provide the ability to reduce the amount of back-to-back multiplexing, and more importantly, network providers can reduce the operation cost of the network.

25 [0006] The SONET standards ANSI T1.105 and Bellcore GR-253-CORE, define the physical interface, optical line rates known as optical carrier (OC) signals, a frame format, and an OAM&P protocol. Opto/electrical conversion takes place at the periphery of the SONET network, where the optical signals are converted into a standard electrical format called the synchronous transport signal (STS), which is the equivalent of the optical signal. Namely, the STS signals are carried by a respective optical carrier, which is defined according to the STS that it carries. Thus, an STS-192 signal is carried by an OC-192 optical signal.

30 [0007] The STS-1 frame consists of 90 columns by 9 rows of bytes, the frame length is 125 microseconds. A frame comprises a transport overhead (TOH) occupying 3 columns by 9 rows of bytes, and a synchronous payload envelope (SPE) occupying 87 columns of 9 rows of bytes. The first column of the SPE is occupied by path overhead bytes.

35 [0008] As such, an STS-1 has a bit rate of 51.840 Mb/s. Lower rates are subsets of STS-1 and are known as virtual tributaries (VT), which may transport rates below DS3. Higher rates, STS-N, where N=1, 3, 12, ...192 or higher, are built by multiplexing tributaries of a lower rate, using SONET add/drop multiplexers. An STS-N signal is obtained by interleaving N STS-1 signals. For example, an STS-192 is made of 192 STS-1 tributaries, each separately visible, and separately aligned within the envelope. The individual tributaries could carry a different payload, each with a different destination.

40 [0009] The STS-N has a TOH made of all N TOHs of the individual tributaries, and a SPE made of all N SPEs of the tributaries, each with its own POH.

[0010] Some services, that operate at a higher rate, are transmitted in an STS-Nc signal (c for concatenation). The STS-1s into the STS-Nc signal are kept together. The whole envelope of the STS-Nc signal is routed, multiplexed and transported as a single entity rather than as N individual entities. The TOH and the start of the SPE for the N constituents are all aligned, since all the constituents are generated by the same source, with the same clock. The first STS-1 in the concatenated signal carries the single set of POH, all that is required for an STS-Nc.

45 [0011] Mapping of one rate or format into another is well known. Bellcore TR-0253 describes in detail the standard mappings of the common asynchronous transmission formats (DS0, DS1, DS2, DS3, etc) into SONET. Similar mappings are defined for the ETSI hierarchy mapping into SDH. Optical transmission equipment has mapped one proprietary format into another. For example, FD-565 could carry Nortel's FD-135 proprietary format as well as the DS3 standard format.

50 [0012] However, the standards or proprietary schemes allow transportation of a very specific set of signals, with format specific hardware. These methods of mapping cannot be used to map rates that vary significantly from the standard. Furthermore, these mappings are each precisely tuned for a particular format and a particular bit-rate, with e.g. a $\pm 20\text{ppm}$ tolerance. If a signal has, for example, a bit rate even 1% different than that of a DS3, cannot be transported within SONET. In addition, a different hardware unit is generally required to perform the mapping of each kind of signal.

55 [0013] A solution to the above problem is to add a "wrapper" to an arbitrary continuous signal. The rate of the resulting signal is a function of the signal being wrapped. Namely, a 1 Mb/s wrapper added to a signal of rate X produces a format with rate X+1 Mb/s. A variation on this adds a percentage of X. For example, a common line coding 8B/10B

produces a format with a rate of 112.5% of X. As such, the "wrapper" methods do not produce formats that have a pre-defined fixed bit rate for arbitrary inputs. The resulting signal cannot in general be time multiplexed to be transported on a high speed network.

[0014] United States Patent No. 5,784,594 (Beatty) proposes a "TDM Wrapper" format where an arbitrary signal is mapped into as much of a frame as required, and the rest of the frame is left empty. However, this method requires a very large memory for each direction of conversion to hold the bits while waiting for the appropriate time slot to transmit them. As a result, this format is expensive to implement with high speed signals.

[0015] Packet or cell based formats map arbitrary input streams into SONET and SDH. While adequate for packet systems, these methods do not meet the jitter or wander requirements of most continuous signal formats due to the "one size fits all" mapping methods used. The clock phase information of the input signal is effectively eliminated in these methods, and so cannot be transmitted.

[0016] US Patent Application 09/307812 (Solheim et al., entitled "Protocol Independent sub-rate device" filed on May 10, 1999 and assigned to Nortel Networks Corporation) discloses a method of transporting different type of clients (IP, ATM, SONET, Ethernet, etc.) together. The '812 application discloses time-multiplexing lower speed (substrate) channels of arbitrary rates and formats into a single higher speed channel, and then demultiplexing the channels at the far end of the system. The portion of the bandwidth assigned to any given substrate channel can be provisioned without any change to the hardware or software. This significantly simplifies and speeds the provisioning of these services by the carrier. Tributaries with new protocols can be accommodated as well, significantly speeding up the delivery of support for these new protocols.

[0017] There remains a need for an efficient method and apparatus that will map arbitrary signals into SONET such that the signals can be recovered with low timing jitter at low cost.

[0018] Accordingly, the invention comprises a method for transmitting a continuous digital signal of an arbitrary rate R1 over a synchronous network as a transparent tributary, selecting a fixed length container signal of a rate R, where R is higher than the arbitrary rate R1 of the continuous signal, and at a transmit site, distributing the bits of the continuous signal into valid timeslots of a frame of the container signal and providing stuff bits into invalid timeslots, wherein the invalid timeslots are uniformly interspersed across the frame.

[0019] The method of the present invention maps arbitrary signals having a continuous format into a SONET frame. This allows any qualified format to be transparently transported within a SONET network.

[0020] The invention further comprises a synchronizer for mapping a continuous format signal of an arbitrary rate for transport over a synchronous network as a transparent tributary signal, comprising a data recovery unit for receiving the continuous format signal and recovering a stream of data bits and a data clock indicative of the arbitrary rate, a receiver buffer unit for receiving the stream of data bits, determining a phase difference between the arbitrary rate and the rate of a frame of the tributary, and generating a control function β , a mapping unit for extracting the stream of data bits from the receiver buffer unit at a mapping clock rate, and uniformly distributing a count of stuff bits and data bits into the frame at a block clock rate according to the control function β .

[0021] According to another aspect of the invention there is provided a de-synchronizer for reverse mapping a continuous format signal of an arbitrary rate received over a synchronous network as a transparent tributary signal, comprising, a reverse mapping unit for receiving a frame of the tributary at a block clock rate and a control function β , and extracting a stream of data bits at a mapping clock rate, while excluding stuff bits according to the control function β , a transmitter buffer unit for receiving the data bits, and determining a phase difference between the arbitrary rate and the rate of the frame, and a data transmit unit for receiving the data bits and transmitting the continuous format signal at a data rate controlled by the phase difference.

[0022] Advantageously, the method of mapping according to the invention allows use of a common technology, such as SONET, for transparently transporting tributaries of same or different formats. Almost any continuous format could be transported by SONET using this novel mapping, without changing any bit. Another advantage of the present invention is that the jitter or wander added by the method is minimal.

[0023] The synchronized/desynchronizer according to the invention handles signals whose format is unknown at the time of design, as long as the jitter tolerance and generation specifications are compatible with the very accommodating range designed into the unit. This is a proprietary mapping, that is designed on the fly by the trib software, and is communicated within the channel to the corresponding trib at the far end.

[0024] Examples of the invention will now be described in detail with reference to the accompanying drawings in which:

Figure 1A is a block diagram of a communication network with the mapping system according to the invention;

Figure 1B is a OC-192c frame, showing the blocks according to an embodiment of the invention;

Figure 1C shows an example of the structure of a block;

Figure 2 illustrates a block diagram for a synchronizer according to an embodiment of the invention; and

Figure 3 shows a block diagram for a de-synchronizer according to an embodiment of the invention.

- [0025] The mapping system according to the invention maps a digital signal that has a constant line rate, up to the designated maximum capacity, into a SONET envelope of a provisioned size. A mapping function could be performed in a tributary unit of a SONET transport shelf, and the reverse mapping function (also called de-mapping) could be performed in a similar unit at the far end of a SONET connection.
- 5 [0026] Figure 1A shows a block diagram of an exemplary transmission system with the mapping system according to the invention, transparently transporting a plurality of services over a SONET network. Only one direction of transmission, as shown by the arrows, is illustrated on this figure for simplification.
- 10 [0027] Signals $S_1, \dots, S_j, \dots, S_n$, where n is the number of the tributaries and j is the range of a tributary, are carried between two sites **A** and **B** into a SONET signal S , over a SONET network 7. Signals S_1, \dots, S_n are digital signals of a continuous format, and are treated at the nodes **A** and **B** as tributaries of SONET signal S . We also note the rate of each signal S_j with R_j and the rate of signals S with R . Signals S_j can carry the same or different type of services. Each trib receiver 1 - 1_n recovers the data bits for the respective continuous format signal S_1, \dots, S_n . Node **A** is provided with one or more synchronizers 20₁-20_n, each synchronizer 20_j for mapping the data bits of corresponding trib signal S_j into a SONET envelope of an appropriate size.
- 15 [0028] The size of the frame to carry transparently the continuous signals between certain transmission nodes is selected in software, and is provisioned having in view a satisfactory bandwidth usage for a large range of continuous format signals. For example, if a nxSTS-12 is used for the envelope, n is between four and twenty for a high speed variant of the synchronizer, and between one and five for a medium speed variant. This avoids stranding significant network capacity.
- 20 [0029] After each signal was mapped into a respective SONET envelope, the tributaries are multiplexed by a SONET multiplexer 3 into a high rate signal S , which is launched by a SONET transmitter 5 over optical network 7 towards site **B**.
- [0030] The reverse operation is performed at site **B**. Namely, the optical receiver 9 recovers the data in signal S , demultiplexer 3' separates the signals and presents them to a respective de-synchronizer 40-40_n. Each de-synchronizer 40_j re-arranges the bits in the respective format associated with the signal S_j , which is presented to a trib transmitter 11_j. Each trib transmitter 11-11_n launches the respective signal S_1, \dots, S_n on the associated trib network, or to an associated end user.
- 25 [0031] An example of a mapping algorithm is provided next for an STS-192c signal, for showing the basic concepts and the feasibility. Other envelopes can also be used, the invention not being limited to the STS-192c signals.
- 30 [0032] Figure 1B shows an STS-192c frame 1, comprising TOH 2, and the STS-192c SPE (synchronous payload envelope) 4. The payload comprises $192 \times 87 \times 9 \times 8 = 1,202,688$ bits.
- 35 [0033] A block 10-j is defined herein as a 1056-bit field, which comprises data bits, fixed stuff bits and adaptive stuff bits, as it will be seen later. An STS-192 SPE can accommodate 1138 such blocks 10-1 to 10-K (where K=1138), that occupy the area shown in grey and designated by reference numeral 8. Block field 8 has 1,201,728 bits. The remaining 960 bits in the envelope 4 are comprised by the POH bits 6 ($9 \times 8=72$ bits) and a remainder field 14 of 888 bits. The number of the bits in fields 6 and 14, is unchanged, irrespective of the rate R_1 of the continuous format signal mapped into the SONET frame 1. Therefore, these bits are called in the following fixed stuff bits.
- 40 [0034] On the other hand, the number of stuff bits necessary to fill the block field 8 varies function of the rate R_1 of the continuous format signal S_1 . These stuff bits are called herein adaptive stuff bits.
- [0035] According to the invention, the data bits of the signal S_1 are mapped into frame 1 with evenly interspersed fixed stuff bits and adaptive stuff bits. These stuff bits are distributed uniformly within each block, on the fly, since the rate R_1 may not be known in advance. Therefore, the synchronizer defines a valid location, that is a location for a data bit, and an invalid location, that is a location for a stuff bit for the next block, based on phase information accumulated when the data bits of the current block are mapped. In addition, the synchronizer also distributes evenly the overhead bits at the time of the actual mapping, but realigns these in the timeslots provided according to the SONET standard after mapping operation, so that the frame is recognized by the SONET equipment. At the far end, the synchronizer effects the reverse operation, by absorbing the fixed stuff bits and the adaptive stuff bits, so that the data bits can be reverse-mapped to regenerate S_1 .
- 45 [0036] It is to be noted that Figure 1B shows the structure of a frame intuitively; in accordance with this invention the mapping algorithm distributes the fixed stuff bits and the adaptive stuff bits uniformly within the frame 1. We also note that the above calculations are applicable to a STS-192c frame; similar consideration apply to other SONET signals.
- 50 [0037] The bits in each block are allocated as shown in Figure 1C. A block 10-1 comprises a data field 17 having 1023 ($2^{10}-1$) bits for data, a control field 13 having 16 bits, and a spare field 15 having 17 bits for future use.
- 55 [0038] The 1023 bits of field 17 provide a bit rate of 9,313.392 Mbps ($1023 \times 1138 \times 8000$) for transportation of the data into a STS-192c frame. The size of the frame is provisioned and fixed for a certain application, i.e. tributaries of arbitrary rates are mapped in frames of a same size. The mapping technique is adaptive for any trib, rather than a different frame being used for every trib. If a trib has a lower rate than 9,313.392 Mbps, it must be justified into the STS-192c, changing more of the bits of data field 8 into stuff bits. Figure 1C illustrates field 19 within field 17, of a variable size v, which size is determined during mapping by comparing the phase between the clock of signals S_1 to

that of signal S.

[0039] Field 13 comprises a 10-bit control function β . The size of β was selected in accordance with the size of the block, so as to uniquely determine the position of valid bits in the next block, according to the adaptive stuffing algorithm below. A 10-bit number can assume 1024 values, which is one more than the size of a block. The value of β also gives the number of the valid bits in the next block. The additional 6 bits of field 13 are necessary for single bit error correction and multiple error detection.

[0040] In case of detection of multiple errors, the β from the previous block is used as the default, for fast reframing downstream with a minimal PLL transient. The bits of fields 15 and 19 are interspersed within the block.

[0041] The value of β may change between adjacent blocks, as not all blocks have the same number of adaptive stuff bits, but β remains constant within each block.

[0042] The adaptive stuffing algorithm defines the binary bit reversal of β which is denoted with α . That is, the most significant bit of β becomes the least significant bit of α ; similarly the least significant bit of α becomes the most significant bit of β . Table 1 details this translation by way of examples.

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Table 1.

Determination of α		β								α											
		β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}	β_{10}	β_8	β_7	β_6	β_5	β_4	β_3	β_2	β_1	
0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
1	0	1	0	1	0	1	0	1	0	0	0	0	1	0	1	0	1	0	1	0	1
0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0

- [0043] α is also determined on a per block basis, and as in the case of β , the value of α may change between the adjacent blocks but does not change within a block.
- [0044] Also defined herein is a counter C , and a value D . C is the counter of bits in a block, and is represented by a 10 bits binary number. C increments from 1 to 1023, and as such identifies the timeslot occupied by a bit in the block.
- 5 [0045] D is the bit-wise transition delta of C , and is represented by a 10 bit binary number with exactly one bit set. This set bit is in the position of a 0 - to - 1 transition that occurs when counter C advances with one bit. Using Boolean functions, each bit of D is given by the bits of range n and $n-1$ of counter C , according to the equation:

$$10 \quad D_n = C_n \text{ AND NOT } (C-1)_n \quad \text{EQ1}$$

[0046] Table 2 gives examples of the values assumed by D for a given value of C .

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Table 2.

Determination of D for a given C											$D_{1,2,\dots,n}$ Bit-wise transition Δ of C									
$C_{1,2,\dots,n}$ Counter of bits in the block											$D_{1,2,\dots,n}$ Bit-wise transition Δ of C									
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}
C-1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
C	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
C+1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
C+2	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1

[0047] In order to spread stuff bits more or less evenly among valid data in the block, the adaptive stuffing algorithm according to the invention states that a bit is valid when a bit in D is also set in α .

[0048] This can be described as in Eq2, for the C^{th} bit of a block:

$$5 \quad \text{Valid}(C, \beta), \text{ if any bit of } (\alpha_{1,2,\dots,n} \text{ AND } D_{1,2,\dots,n}) \text{ is non zero} \quad \text{Eq2}$$

[0049] A valid bit corresponds to a bit which is assigned to data, and consequently an invalid bit corresponds to a stuff bit. Table 3 shows a simple example of how the algorithm works for a block with 7 bits, for which size of β is 3 bits. It is to be understood that the algorithm operates in a similar way for blocks of 1023 bits and a 10-bit β , but it is impractical to detail the full stuffing sequences in this specification.

[0050] The entries in Table 3 are the result of the binary function $\text{Valid}(C, \beta)$. The columns illustrate how data and stuff bits are interspersed for a particular number of valid bits in the block, as given by β .

[0051] For each value of C where $\text{Valid}(C)$ is true, a valid data bit is present in the timeslot identified by C , for each untrue value of $\text{Valid}(C)$, a stuff bit is placed into the timeslot. Using this scheme, the invalid stuffing bits are spread almost uniformly through the frame.

Table 3.

Example of flexible mapping for a 7-bit block, for a 3-bit β										
		β	000	001	010	011	100	101	110	111
		α	000	100	010	110	001	101	011	111
C		D	Valid(C, 0)	Valid(C, 1)	Valid(C, 2)	Valid(C, 3)	Valid(C, 4)	Valid(C, 5)	Valid(C, 6)	Valid(C, 7)
1		001	001	Stuff	Stuff	Stuff	Data	Data	Data	Data
2		010	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
3		011	001	Stuff	Stuff	Stuff	Data	Data	Data	Data
4		100	100	Stuff	Data	Stuff	Data	Stuff	Data	Data
5		101	001	Stuff	Stuff	Stuff	Data	Data	Data	Data
6		110	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
7		111	001	Stuff	Stuff	Stuff	Data	Data	Data	Data

[0052] In this example, counter C counts from 1 to 7 and D is evaluated in the respective column, for all values of C . Each value of D , as C increments, is then compared with α . If the set bit in D is also set in α , the corresponding C^{th} bit in the block will be a data bit. If the set bit in D is not set in α , the corresponding C^{th} bit in the block will be a stuff bit.

[0053] Let's take as an example a block where the bit rate $R1/R$ is $5/7^{\text{th}}$ of the available capacity, which means that β is binary 5(101), and α , the binary bit reversal of β , is also 5 (101). The sequence of data and stuff bits in the block is as per column Valid(C,5) and is:

Data, Stuff, Data, Data, Data, Stuff, Data

[0054] It is also apparent on Table 3 that for $\text{Valid}(C,5)$ β , which is five, is also the number of valid bits, and the invalid bits are spread almost uniformly through the frame.

[0055] Table 4 details the stuffing sequence for 5 consecutive blocks, with a slightly different between blocks. In this Table, counter C counts from 1 to 7, and two consecutive blocks are shown with a different background (grey and white) for clarity.

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Table 4.

Adaptive Stuff algorithm for five consecutive 7-bit blocks,										
5		β	000	001	010	011	100	101	110	111
		α	000	100	010	110	001	101	011	111
10	C	D	Valid (C,0)	Valid (C,1)	Valid (C,2)	Valid (C,3)	Valid (C,4)	Valid (C,5)	Valid (C,6)	Valid (C,7)
		1	001	001	Stuff	Stuff	Stuff	Data	Data	Data
15	2	010	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
20	3	011	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
25	4	100	100	Stuff	Data	Stuff	Data	Stuff	Stuff	Data
30	5	101	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
35	6	110	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
40	7	111	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
45	1	001	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
50	2	010	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
55	3	011	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	4	100	100	Stuff	Data	Stuff	Data	Stuff	Stuff	Data
	5	101	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	6	110	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
	7	111	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	1	001	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	2	010	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
	3	011	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	4	100	100	Stuff	Data	Stuff	Data	Stuff	Stuff	Data
	5	101	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	6	110	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
	7	111	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	1	001	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	2	010	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
	3	011	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	4	100	100	Stuff	Data	Stuff	Data	Stuff	Stuff	Data
	5	101	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	6	110	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
	7	111	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	1	001	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	2	010	010	Stuff	Stuff	Data	Data	Stuff	Data	Data
	3	011	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	4	100	100	Stuff	Data	Stuff	Data	Stuff	Stuff	Data
	5	101	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data
	6	110	010	Stuff	Stuff	Data	Data	Stuff	Data	Data

Table 4. (continued)

Adaptive Stuff algorithm for five consecutive 7-bit blocks,										
		β	000	001	010	011	100	101	110	111
		α	000	100	010	110	001	101	011	111
C		D	Valid (C,0)	Valid (C,1)	Valid (C,2)	Valid (C,3)	Valid (C,4)	Valid (C,5)	Valid (C,6)	Valid (C,7)
7	111	001	Stuff	Stuff	Stuff	Stuff	Data	Data	Data	Data

[0056] As indicated above, β is set for each block, but may vary between subsequent blocks, since the ratio between the total number of stuff bits and the number of blocks may not be an integer. Let's consider the following example:

- 15 block 1 (grey) has a β of 5
- block 2 (black) has a β of 6
- block 3 (grey) has a β of 5
- block 4 (black) has a β of 5
- block 5 (grey) has a β of 6

20 [0057] In this case, the spreading of stuff bits among data bits is as follows:

DSDDDS DDDSDDD DSDDDS DSDDDSD DDDSDDD

where D stands for data, and S for Stuff. To avoid confusion between D and S above, they are written in regular characters, while italic characters are used for signals *S*, and for *D*, bit-wise transition Δ of *C*.

25 [0058] It is again evident from Table 4 that the stuff bits are spread more or less evenly among the data bits, even with a slight variation of β .

30 [0059] Figure 2 illustrates a block diagram of a trib synchronizer 20. Transparency is obtained as discussed above, by filling a SONET SPE with data received at an arbitrary rate. The data path is illustrated using wide arrows, and reference numerals 22 and 22'. Signal S_1 of a continuous format and rate $R1$ is detected by a data recovery unit 36. The data bits then pass through a fill control unit 38, a mapping unit 30, a receiver overhead FIFO (first-in, first-out) 31, and an overhead multiplexer 33. The signal output by synchronizer 20 is now in a SONET frame. It is to be understood that signal S has a SONET-type overhead (TOH and POH) with the respective OAM&P information, and has a SONET rate R , while the placement of the bits into the synchronous payload is according to the mapping algorithm rather than to the SONET standard.

35 [0060] Synchronizer 20 manipulates four different clocks: a data clock 24, a block clock 26, a mapping clock 32 and SONET clocks 28 and 28A. Clock 28 has the STS-192 rate and clock 28A has the rate of the frame. The data clock 24 (rate R1) is recovered from the incoming data by data recovery unit 36 which comprises a receiver 21 and a flexible clock recovery circuit 25. Flexible clock recovery circuit 25 is capable of clock recovery over a broad continuous range of bit-rates. An example of such a circuit is disclosed in the co-pending US Patent application 09/218053 filed on December 22, 1998, entitled "Apparatus and Method for Versatile Digital Communication, by Habel et al., assigned to Northern Telecom Limited. Patent application '053 is incorporated herein by reference.

40 [0061] A certain set of known signal formats could be recognized by an off-line framer 39, shown in dotted lines on Figure 2, and frame and BER performance information reported. Also, line coding could be removed from some signals at the receiver and added on at the transmitter, for better efficiency in mapping. These options depend on the particular type of service, and therefore are not discussed in further detail here.

45 [0062] A receiver buffer unit 38 comprises an elastic store 23 and a receiver digital PLL 29. The data clock 24 is used to clock the input of data into elastic store 23, which is emptied under control of mapping clock 32. Mapping clock 32 is a gapped clock, derived from the STS-192 clock 28. This clock is discontinued at appropriate phase instants as determined by the mapping algorithm, in addition to the gaps in the block clock. In this way, data 22 is synchronized to the mapping frequency at the input of mapper 27.

50 [0063] If the payload field 4 were filled continuously with data bits to the capacity required, and the remaining capacity were a continuum of stuff bits, the elastic store 23 fill would vary widely, requiring a rather large depth for the store 23. The elastic store 23 would fill rapidly while stuff bits are loaded, emptying rapidly while a continuous stream of trib data bits are loaded. This situation is avoided in the configuration of Figure 2, where the elastic store 23 is emptied at substantially regular intervals by mapping clock 32.

55 [0064] On the other hand, the elastic store 23 must be sufficiently deep to absorb all input jitter and wander from the trib. If the fill of the elastic store 23 is sufficiently well controlled, it can be guaranteed never to overflow or underflow even in the presence of worst-case jitter and wander, and the synchronizer 20 will still meet jitter tolerance requirements.

Experimentally the minimum size of the elastic store 23 was determined at 256 bits.

[0065] Receiver digital PLL 29 controls the rate at which the elastic store is emptied to maintain the optimal fill by way of β which determines the mapping clock 32. In other words, the average rate of mapping clock 32 is controlled to track the average rate of data clock 24 and β results from the phase difference between these clocks. As indicated above, β controls filling of the next block. This control has the advantage that the synchronizer 20 does not need a pointer adjustment as per SONET standard. Rather, control of the elastic store fill ameliorates any line and trib rate variations with time (line and trib jitter and wander), as long as the maximum trib rate never exceeds the payload rate.

[0066] To determine β , the input to the elastic store 23 is sampled periodically and phase information on data 22 is input to PLL 29. The digital PLL 29 may for example comprise a 24-bit accumulator. At the start of the block, the fill of the elastic store 23 given by counter C of mapper 27 is latched relative to e.g. 50%. Then, the phase of sample 34 is incremented into the accumulator and added to the phase left-shifted by 3 bits. The upper 10 bits of this sum S is β . The accumulator must be clipped at FFFFFF to not roll-over, and clipped at a lowest value such as 400000 to reflect the low frequency limit of the analog output PLL range. Other implementations of digital PLL are also possible.

[0067] If the elastic store 23 starts to overflow, β would be increased to empty the store by speeding-up the mapping clock 32. Similarly, if store 23 begins to empty, β would be decreased to allow store 23 to fill. The target fill is preferably 50%.

[0068] Mapping unit 30 comprises a block clock gapper 37, a mapping clock gapper 35 and a mapper 27.

[0069] Block clock gapper 37 receives the STS-192 clock 28 which features gaps and regular cycles accounting for SONET TOH. Clock 28 generates the block clock 26, which has in the above example 1138 (number of blocks) \times 1056 (size of a block) = 1.201.728 cycles per SONET frame, with 42,432 gaps spread evenly through the frame. As indicated above, the gaps of the block clock 26 are due to the SONET overhead, namely field 2 in Figure 1B, whose size is $3 \times 9 \times 8 \times 192$, and to the fixed stuffing, namely fields 6 and 14, whose size is 960. Block clock 26 represents the total allocation of bits in field 8. In other words, block clock 26 is discontinued at approximately every 30th bit to keep room for the TOH bits, POH bits and the fixed stuff bits, in the case when the overhead size of the frame is according to the SONET standard.

[0070] Mapping clock gapper block 35 has the same rate as the block clock, but is further gapped under control of β , as described above, with a pulse at every valid bit location, to further account for the adaptive stuff bits resulted from the difference between rates R1 and R.

[0071] Mapper 27 takes mapping clock 32, block clock 26 and some other complementary clocks, not shown for simplicity, and justifies data 22 using both fixed and adaptive stuff bits. The data bits are clocked out from elastic store 23 into the mapper using mapping clock 32. The data bits, fixed and adaptive stuff bits are clocked out from mapper 27 using block clock 26. The mapper 27 has essentially no memory, the elastic store 23 and the FIFO 31 representing all the memory of the synchronizer.

[0072] The bits from mapper 27 denoted with reference numeral 22', as they comprise data, fixed and adaptive stuff bits, are clocked into the receiver overhead FIFO (first-in first-out) 31, which reserves timeslots for the SONET overhead locations. Next, bits 22' are clocked out of FIFO 31 with clock 28A, whereby FIFO 31 is reset synchronously once each frame. The depth of FIFO 31 has only to be sufficient to store payload bits during the phase instants of the frame when frame OH is being clocked into the OH MUX. If the frame has the same OH to payload ratio as SONET, this depth must be greater than $192 \times 8 \times 9 \times 3$ bits, and is preferably larger than $192 \times 8 \times 12 \times 3$ bits.

[0073] From FIFO block 31, bits 22' are clocked into the SONET overhead multiplexer 33 where the SONET overhead is added in the respective empty timeslots and the signal is then treated as an STS-192. The SONET clocks 28 and 28A, shown in thin lines, are locked to the rest of the shelf, in the usual manner.

[0074] A serial hardware implementation is described for simplicity. Parallel implementations of this kind of mapping, such as byte wide implementations can obtain lower clock speeds. These parallel implementations can have staggered block alignments for reduced jitter. DSP control rather than hardware control would give greater freedom to optimize the PLLs.

[0075] Figure 3 shows the block diagram of the transmitter side of the transparent reverse synchronizer, or desynchronizer 40. The desynchronizer 40 performs the inverse function performed by the synchronizer 20, in a very similar manner, and is provided with similar blocks.

[0076] A SONET overhead demultiplexer 53 delineates the SONET overhead from signal 42' using STS-192 clock 28, which is locked to the rest of the shelf in the usual manner. A transmitter overhead FIFO 51 is reset synchronously once each frame with clock 28A. Overhead FIFO 51 absorbs overhead locations so as to present to the mapper 47 the data 42' received in the payload, comprising data bits together with the fixed stuff bits and adaptive stuff bits.

[0077] If pointer adjustment is not considered, the transmitter OH FIFO 51 could have a similar depth with that of receiver OH FIFO 31 of synchronizer 20. For example, if the SONET OH is used for the frame, the required depth is, as in the case of FIFO 31, $192 \times 8 \times 12 \times 3$ bits. FIFO could thus store sufficient data bits so that transmitter OH FIFO 51 is not emptied during the frame phase when the OH is being demultiplexed from the bit stream. However, as pointer alignment is necessary for the desynchronizer, the transmitter OH FIFO 51 must have additional depth to tolerate the

worst-case series of positive or negative pointer adjustment events.

[0078] A reverse mapping unit 50 comprises a reverse mapper 47, a mapping clock gapper 55, and a block clock gapper 57.

[0079] The block clock gapper 57 gaps the STS-192 clock 28 to create block clock 26. Block clock 26, as in the case of the synchronizer 20, has 1,201,728 cycles per frame, with 42,432 gaps spread evenly across the frame. The gaps account for fields 2, 6 and 14 of Figure 1B. In other words, this clock rejects the TOH and the fixed stuff bits.

[0080] Block clock gapper 57 of the desynchronizer also includes/deletes gaps for pointer adjustments. These inclusions must be spread out for three frames to minimize the phase hit from a pointer adjustment.

[0081] Mapping clock gapper 55 receives the block clock 26 and β , read from an in-band OH channel within the block. Using β , gapped clock 26 is further gapped to produce the mapping clock 32. Mapping clock 32 gaps-out data bits 42' so that strictly trib data bits 42 are clocked out.

[0082] Bits 42 are next processed by a transmitter buffer unit 54, which comprises an elastic store 43 and a transmitter digital PLL 49. The trib data bits 42 are clocked into the output elastic store 43 using mapping clock 32. The elastic store 43 is emptied by the data clock 24, output by the flexible clock recovery circuit 45.

[0083] The phase of the output elastic store 43 is sampled periodically by the transmitter digital PLL. The sample 34 is processed digitally, and an output signal passed to the flexible clock circuit 45, to control the voltage of the VCO. The flexible clock circuit 45 is of a similar type with the flexible clock circuit 25 of the synchronizer, and provides data clock 24.

[0084] The bandwidth of the Tx PLL 49 must be as low as possible to filter out jitter from the mapping and from pointer adjustments, and yet high enough to suppress the VCO noise.

[0085] While the invention has been described with reference to particular example embodiments, further modifications and improvements which will occur to those skilled in the art, may be made within the purview of the appended claims, without departing from the scope of the invention in its broader aspect.

25 Claims

1. A method for transmitting a continuous digital signal of an arbitrary rate R1 over a synchronous network as a transparent tributary, comprising:

30 selecting a fixed length container signal of a rate R, where R is higher than said arbitrary rate R1 of said continuous signal; and

35 at a transmit site, distributing the bits of said continuous signal into valid timeslots of a frame of said container signal and providing stuff bits into invalid timeslots,

wherein said invalid timeslots are uniformly interspersed across said frame.

2. A method as claimed in claim 1, wherein said container signal is a SONET/SDH signal, and said synchronous network is a SONET/SDH network.

40 3. A method as claimed in claim 2, wherein said SONET/SDH signal further comprises a synchronous tributary.

4. A method as claimed in claim 2, wherein said SONET/SDH signal comprises a plurality of transparent tributaries.

45 5. A method as claimed in any preceding claim, wherein said invalid timeslots comprise one of a fixed stuff and an adaptive stuff bit.

6. A method as claimed in claim 5, wherein said step of distributing comprises:

50 receiving a continuous stream of data bits and determining the phase difference between said arbitrary rate R1 and said rate R;

adding to said continuous stream a definite number of timeslots for accommodating said fixed stuff bits within said frame, and an adjustable number of timeslots for accommodating said adaptive stuff bits within said frame, based on said phase difference.

55 7. A method as claimed in claim 6, wherein said adjustable number is substantially larger than said definite number.

8. A method as claimed in claim 6, wherein said definite number includes transport overhead TOH timeslots and

reminder fixed stuff bits timeslots.

9. A method as claimed in claim 8, further comprising providing maintenance, operation, administration and provisioning information in said TOH timeslots.

- 5 10. A method as claimed in any one of claims 6 to 9, wherein said step of adding comprises:

partitioning said frame into a number of equally sized data blocks and said definite number of timeslots; for each block,

- 10 determining the number of fixed stuff bits and evenly distributing said fixed stuff bits within said block; determining a control function β indicative of said adjustable number; and evenly mapping said fixed stuff bits and said adaptive stuff bits uniformly within a next block based on said control function.

- 15 11. A method as claimed in claim 10, wherein said step of mapping comprises:

providing a counter C for identifying a timeslot in said block; defining the binary bit reversal α of said control function β ;

- 20 calculating the bitwise transition delta of said counter C; and determining if a timeslot identified by said counter C is an invalid timeslot, whenever a function Valid (C, β) is false; and

providing an adaptive stuff bit into said invalid timeslot.

- 25 12. A method as claimed in any preceding claim, further comprising recovering said continuous signal from said synchronous signal at a receive site, by extracting the data bits of said continuous signal from said valid timeslots of said frame.

- 30 13. A synchronizer (20) for mapping a continuous format signal of an arbitrary rate for transport over a synchronous network as a transparent tributary signal, comprising:

a data recovery unit (36) for receiving said continuous format signal and recovering a stream of data bits and a data clock indicative of said arbitrary rate;

- 35 a receiver buffer unit (38) for receiving said stream of data bits, determining a phase difference between said arbitrary rate and the rate of a frame of said tributary, and generating a control function β ; a mapping unit (30) for extracting said stream of data bits from said receiver buffer unit at a mapping clock rate, and uniformly distributing a count of stuff bits and data bits into said frame at a block clock rate according to said control function β .

- 40 14. A synchronizer as claimed in claim 13, wherein said receiver buffer unit comprises:

an elastic store (23) for temporarily storing an amount of data bits of said stream at said data clock and providing said data bits to said mapping unit (30) at said block clock rate;

- 45 a digital PLL (29) for determining the phase difference between said arbitrary rate and said mapping clock and providing said control function β .

15. A synchronizer as claimed in claim 13 or 14, wherein said data recovery unit (36) comprises a frequency agile PLL (25) for detecting said arbitrary rate, and a receiver (21) for detecting said data bits using said data clock.

- 50 16. A synchronizer as claimed in claim 13, 14 or 15 wherein said mapping unit (30) comprises:

a block clock gapper (37) for receiving a clock indicative of the rate of said synchronous frame and providing said block clock of a block rate accounting for all timeslots of said synchronous frame and with gaps accounting for a definite number of timeslots for accommodating fixed stuff bits;

- 55 a mapping clock gapper (35) for receiving said block clock and said control signal β and providing a mapping clock of a mapping rate accounting for all timeslots of said synchronous frame and with gaps accounting for an adjustable number of timeslots for accommodating adaptive stuff bits within said frame; and

a mapper (27) for receiving said block clock and said mapping clock and accordingly mapping said stream of data bits in said frame.

17. A synchronizer as claimed in any one of claims 13 to 16, further comprising a receiver OH FIFO (31) for re-arranging a plurality of transport overhead TOH timeslots for seamless transport of said frame within said synchronous network.

5 18. A synchronizer as claimed in claim 17, further comprising an overhead multiplexer (33) for adding operation, administration, maintenance and provisioning data into said TOH timeslots.

10 19. A de-synchronizer for reverse mapping a continuous format signal of an arbitrary rate received over a synchronous network as a transparent tributary signal, comprising:

a reverse mapping unit (50) for receiving a frame of said tributary at a block clock rate and a control function β , and extracting a stream of data bits at a mapping clock rate, while excluding stuff bits according to said control function β ;

15 a transmitter buffer unit (54) for receiving said data bits, and determining a phase difference between said arbitrary rate and the rate of said frame; and

a data transmit unit (52) for receiving said data bits and transmitting said continuous format signal at a data rate controlled by said phase difference.

20 20. A de-synchronizer as claimed in claim 19, wherein said control function β is received in said frame.

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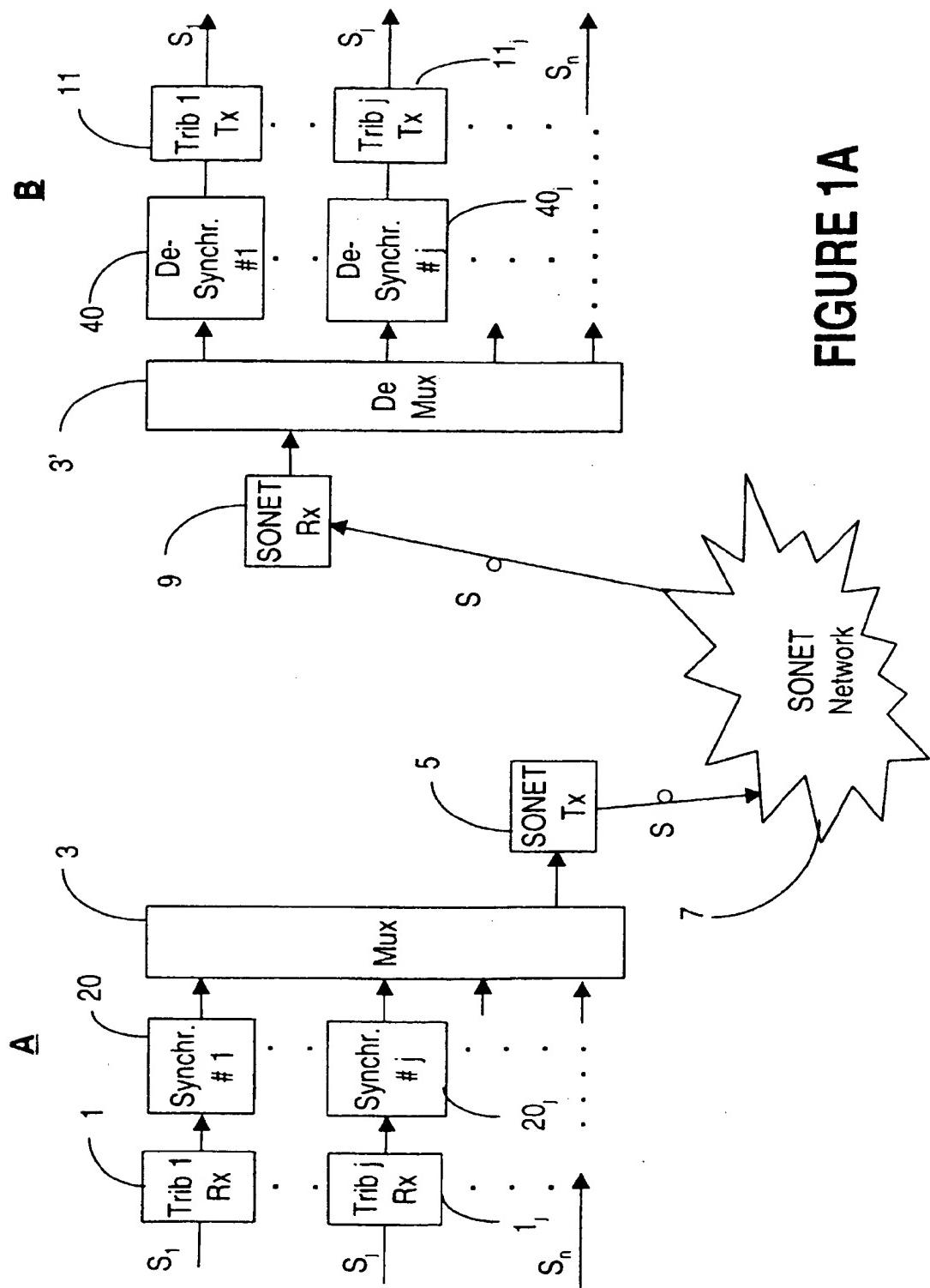


FIGURE 1A

FIGURE 1B

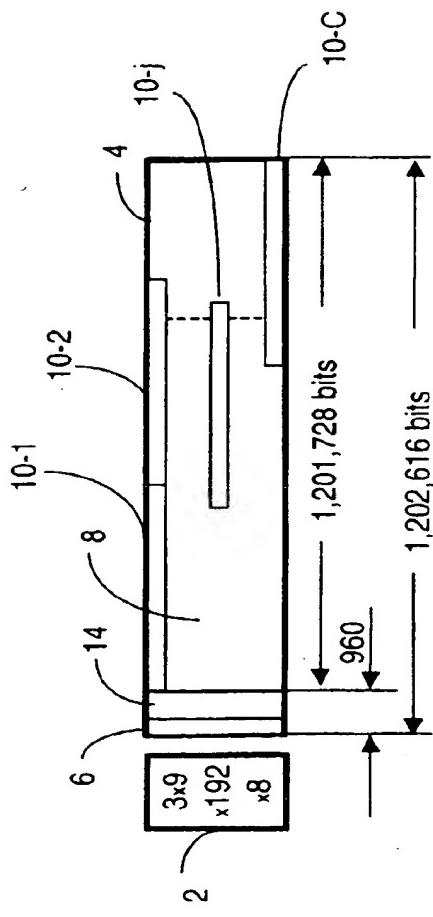


FIGURE 1C

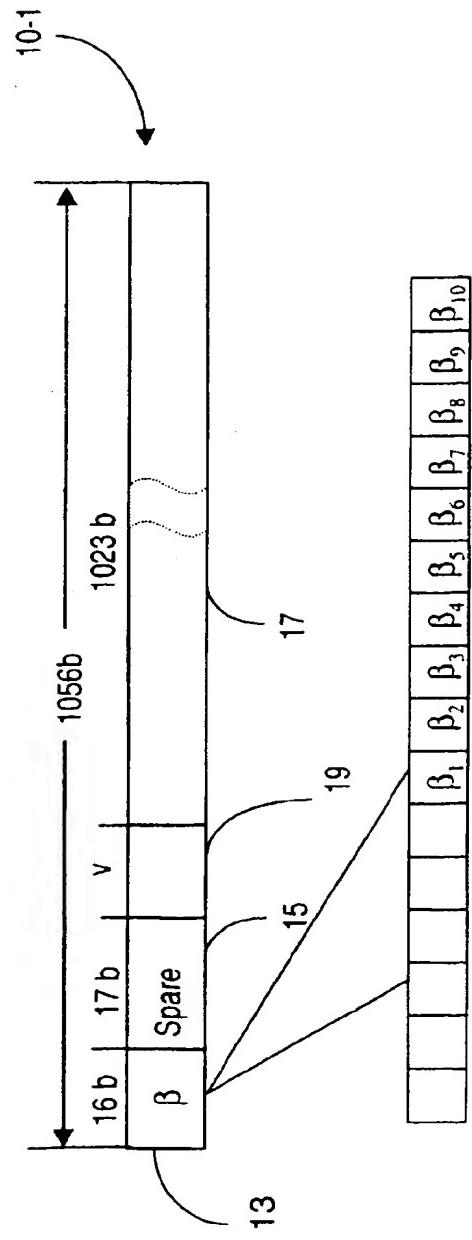


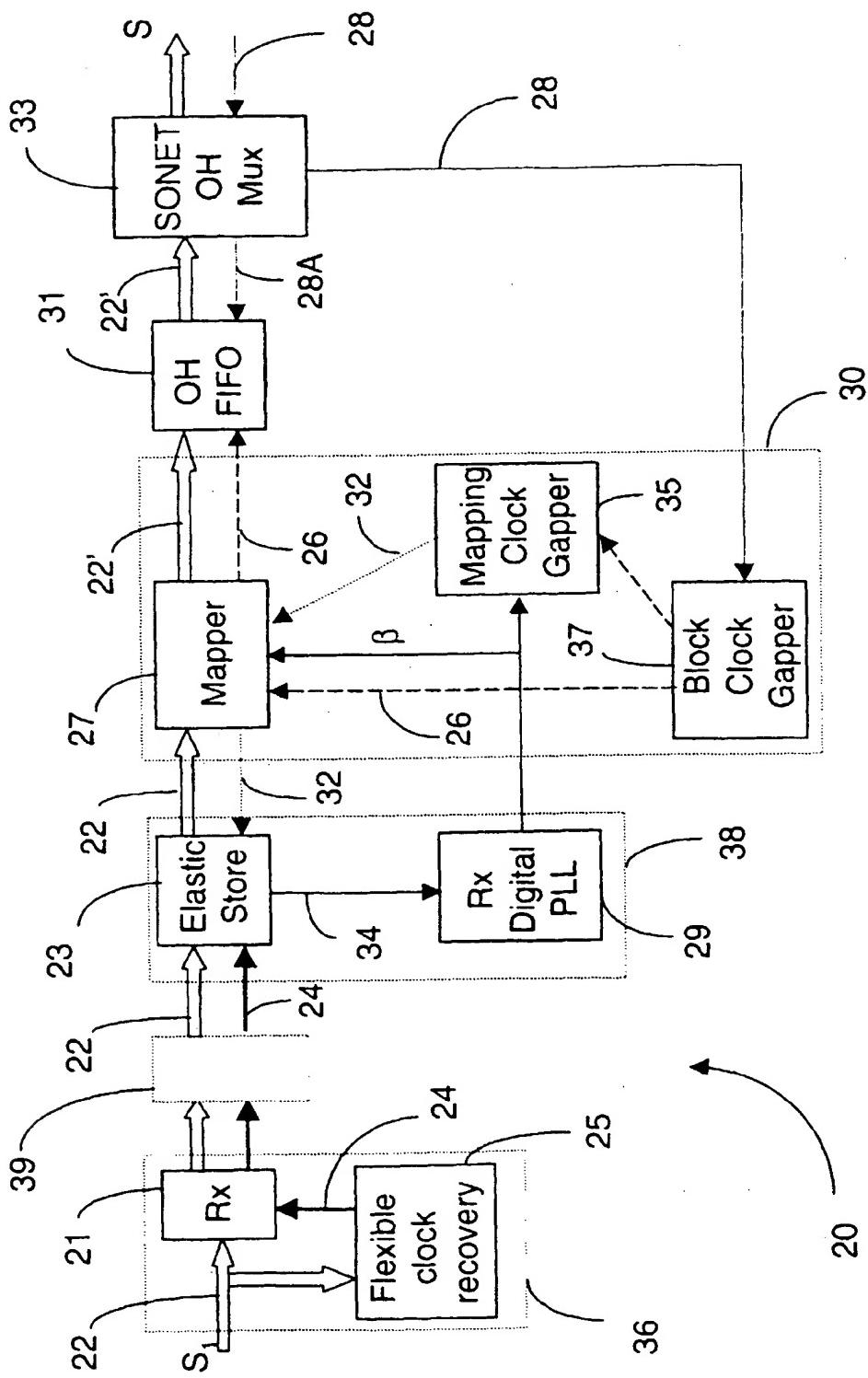
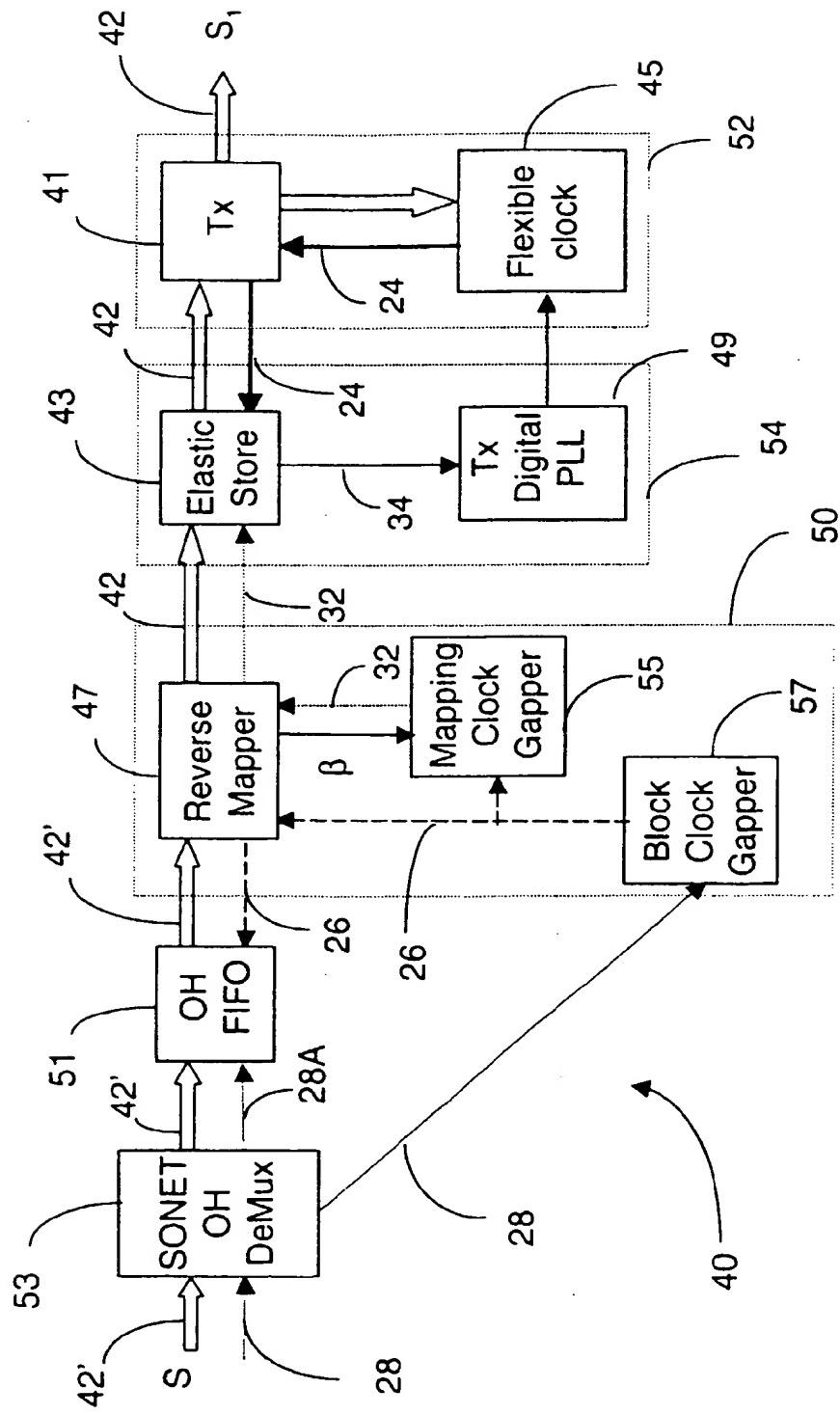
FIGURE 2

FIGURE 3

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(71) Applicant: **Nortel Networks Limited
Montreal, Quebec H2Y 3Y4 (CA)**

(72) Inventor: **Roberts, Kim B.
Nepean, Ontario K2R 1C6 (CA)**

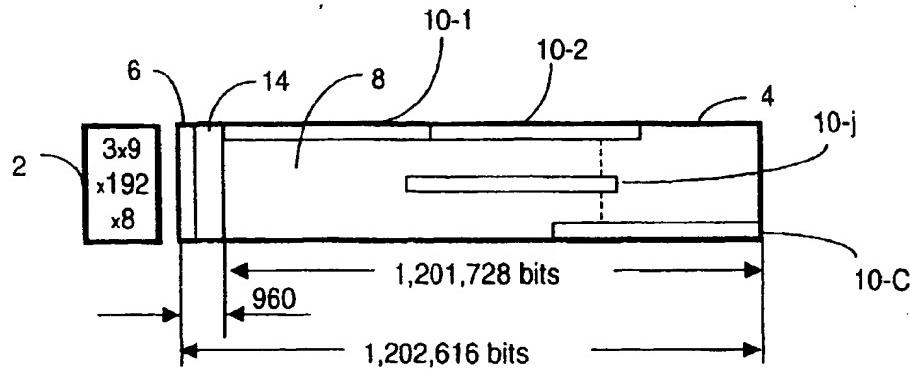
(74) Representative: **Ertl, Nicholas Justin
Elkington and Fife,
Prospect House,
8 Pembroke Road
Sevenoaks, Kent TN13 1XR (GB)**

(54) Mapping arbitrary signals into sonet

(57) A synchronizer/de-synchronizer maps continuous format signals of an arbitrary rate into frames of pre-selected single common rate, such as SONET frames, with no bits changed and very little jitter or wander added. In this way, the continuous format signal may be carried transparently as a tributary of a SONET network. Each frame comprises a definite number of fixed stuff bits (6, 14) including transport overhead bits and re-

minder fixed stuff bits. A frame also comprises an adjustable number of adaptive stuff bits (8), resulting from the phase difference between the arbitrary rate and the common rate. A mapping function is performed in a tributary unit shelf of a SONET transport shelf, and the reverse mapping function is performed in a similar way at the far end of a SONET connection. The stuff bits are spread uniformly within the frame.

FIGURE 1B





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EUROPEAN SEARCH REPORT

Application Number
EP 00 30 5782

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A	US 4 811 340 A (MCEACHERN JAMES A ET AL) 7 March 1989 (1989-03-07) * abstract * * column 2, line 10 - line 61 * * column 3, line 3 - line 45 * * column 6, line 23 - line 51 * * column 8, line 6 - line 63 * ---	1-20 -/-	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H04J						
<p>The present search report has been drawn up for all claims</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">Place of search</td> <td style="width: 33%;">Date of completion of the search</td> <td style="width: 34%;">Examiner</td> </tr> <tr> <td>MUNICH</td> <td>5 August 2002</td> <td>Carballo da Costa, E</td> </tr> </table> <p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the Invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>				Place of search	Date of completion of the search	Examiner	MUNICH	5 August 2002	Carballo da Costa, E
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DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int.Cl.7)						
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim							
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			TECHNICAL FIELDS SEARCHED (Int.Cl.7)						
<p>The present search report has been drawn up for all claims</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">Place of search</td> <td style="width: 33%;">Date of completion of the search</td> <td style="width: 34%;">Examiner</td> </tr> <tr> <td>MUNICH</td> <td>5 August 2002</td> <td>Carballo da Costa, E</td> </tr> </table>				Place of search	Date of completion of the search	Examiner	MUNICH	5 August 2002	Carballo da Costa, E
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